Origin of limestone lenses in Perth Basin yellow sand, southwestern Australia

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Abstract

Aeolian limestone lenses are common in thick sections of yellow quartz sand in the Pleistocene sequences of the Perth Basin, southwestern Australia. Previous workers presumed that these lenses are undigested residuals as the coastal limestones purportedly decalcified to quartz sand. Evidence presented here suggests that the limestone lenses are outliers of calcareous dunes that migrated inland over yellow quartz sand from a Pleistocene coastal zone. Subsequently the lenses were buried by sea-ward influx of yellow quartz sand. This interpretation is based on size, geometry, lithology and stratigraphy of limestone lenses, and their stratigraphic relationships with encompassing yellow quartz sand, and comparisons with geometry, stratigraphy and lithology of Holocene dune deposits.

Introduction

Lenses of aeolian limestone are commonly encountered in thick sections of yellow quartz sand in Pleistocene sequences of the Perth Basin, southwestern Australia. Generally these limestone lenses, also termed "limestone floaters", have been interpreted as undigested residuals of limestone which have formed as the Pleistocene calcareous aeolianites of this region purportedly decalcified to form quartz sand sheets and dunes (McArthur & Bettenay 1960, 1974). Probably the first reference to this process of decalcification is that of Woodward (1890), but subsequent authors have reached similar conclusions or accepted the conclusions of earlier workers (Clark 1926, Crocker 1946, Prider 1948, Fairbridge 1950, 1953, 1954, Fairbridge & Teichert 1953, McArthur & Bettenay 1960, 1974, Welch 1964, Lowry 1967, 1977, Low 1971, Baxter 1972, Johnstone *et al.* 1973, Lissiman & Oxenford 1973, Mulcahy 1973, Mulcahy & Churchward 1973, Wilde & Low 1975, McArthur 1976, Playford *et al.* 1976, and Wyrwoll & King 1985).

This paper presents an important and radically different interpretation of the origin of limestone lenses. It is concluded that limestone lenses in Perth Basin yellow sand, are the buried outliers of attenuated parabolic calcareous dune that have migrated inland from a Pleistocene coastal zone. This interpretation is based on criteria of size, geometry, and stratigraphic relationships of limestone lenses to the surrounding quartz sand, and comparisons with geometry, stratigraphy and lithology of Holocene dunes. Such an interpretation depicts a very different conclusion to the model currently accepted and provides important implications for the stratigraphic relationship of limestone and yellow sand. However, it should be stressed that this paper concentrates on the origin of limestone lenses that occur in yellow sand sequences, and not on the origin of the yellow sand. The origin of the yellow sand as aeolian deposits is discussed later only in the light of the interpretation that limestone lenses are buried Pleistocene calcareous dunes and not undigested residuals.

The philosophy of approach in this paper has been to document the geometry and stratigraphy of Holocene parabolic dunes and their geomorphic variations and diagenesis. This forms the basic foundation work to understanding the origin of limestone lenses, and the information from the Holocene is applied to interpret the Pleistocene sections.

Methods

Stratigraphic information from Holocene quartzose carbonate sand, Pleistocene yellow quartz sand and Pleistocene quartzose limestone (subsequently referred to as limestone) lenses was collected from quarry exposures, road cuts, from drill holes using reverse circulation air coring techniques, and from back-hoe trenches and pits. The limestone lenses were fully excavated in four of the study sites to expose the contact between a limestone lens and underlying yellow sand. The limestone lenses were excavated in short 2 to 3 m long trenches along their bases at the other study sites with information augmented by drilling.

The relationships between Holocene dune sand and Pleistocene units were studied by utilising aerial photographs of the region between Bunbury and Dongara, by topographic levelling to determine cross-sectional relief of Holocene dunes, and by air core drilling, augering and trenching to ascertain thickness, geometry and underlying contact relationships of the Holocene dune deposits.

Samples also were collected for petrographic analyses. This material included *in situ* yellow sand, rhizoconcretions in the yellow sand, calcreted pipes in yellow sand, general samples of friable to indurated Pleistocene limestone, and indurated (sparry calcite cemented) Holocene dune sand.

Geological Setting

The study area is the Swan Coastal Plain which is the coastal lowland stretching from Geographe Bay to Dongara (Fig. 1). The plain is bordered to the east by the Darling Plateau or by the Dandaragan Plateau and Eneabba Plain (Playford *et al.* 1976, Biggs *et al.* 1980). The seaward portion of the Swan Coastal Plain is of relevance to this study because in these locations ridges of the Pleistocene Tamala Limestone (= Spearwood Dunes of McArthur & Bettenay 1960) may interfinger with or lie juxtaposed against Pleistocene yellow quartz sand to the east, and adjoin Holocene dunes of the modern coast to the west (Fig. 1).

The Holocene coastal dune sands, referred to as Safety Bay Sand (Passmore 1970, Playford *et al.* 1976, Semeniuk & Searle 1985), typically are a short-parallel unit of white to cream calcareous quartz sand variable in width and thickness dependent upon coastal type and supply of sand. In many areas the coastal dunes form massive inland migratory parabolic systems that transgress over either earlier Holocene sand sequences or Pleistocene units such as Tamala Limestone and yellow sand.

From a subcontinental perspective it is apparent that the number, attenuation and extent of inland ingress of the Holocene parabolic dunes increase from south to north in response to a more arid climate and more intense wind system (see Fig. 2 of Searle & Semeniuk 1985). Additionally the direction of the parabolic dune axis changes progressively from approximately east-west in southern areas to north-south in northern areas (Fig. 1).

The belt of Tamala Limestone has a shore-parallel trend. The limestone may crop out at the coast, or may be buried by Holocene littoral and coastal dune deposits. The eastern margin of the Tamala Limestone at its contact with Bassendean Sand is more complicated, and is locally sharp, or marked by interfingering, or marked by a zone of lenses.

The lithofacies referred to herein as yellow sand, although typically yellow, also includes sands varying from white to orange to locally red. Yellow sand is predominantly quartz with moderate to trace amounts of feldspar, and minor kaolin, goethite, and heavy minerals (Prider 1948, Baxter 1972, Lissiman & Oxenford 1973, Glassford & Killigrew 1976, Glassford 1980). The term yellow sand as used here is strictly a lithologic term, with no implication as to stratigraphic occurrence. That is, yellow sand does not necessarily belong to any one of the currently defined Quaternary formations. As such it includes the yellow sand portions of the Tamala Limestone (or Spearwood Dunes), the Basssendean Sand, and the Yoganup Formation.

Geomorphic, Stratigraphic & Lithologic Features of Holocene Parabolic Dunes

The geomorphic and statigraphic relationships between Holocene parabolic dunes of the Safety Bay Sand and underlying Pleistocene units were investigated in 5 localities: 1) Mandurah, 2) Trigg Island, 3) Whitfords, 4) Cervantes, 5) Jurien Bay, and 6) Dongara (Fig. 1). The results of the investigations are shown in Fig. 2. The key elements of the Holocene stratigraphic information are summarised in Fig. 3.

The coastal zone of the study areas, encompassing the shoreline and the subaerial strip up to several kilometres inland, consists of an overlapping belt of dune-sand ridges developed as adjacent parabolic dunes have formed and accumulated under the influence of prevailing strong onshore winds. However, distal from the coastal zone there are isolated parabolic dunes extending up to several kilometres inland. The amount of overlap between adjacent parabolic dunes also decreases to landward (Fig. 2). In many areas the attenuated parabolic dunes have become detached from their coastal ridge source to become isolated curved ribbons/shoestrings and conical hills of aeolian sand.

Cross-sectional stratigraphic profiles indicate that in near coastal zones the aeolian ridge consists of overlapping and adjacent parabolic dunes. However to landward, as the overall inland extent of parabolic dune encroachment diminishes, individual isolated parabolic dunes are recognisable with distinct migrating rim, arms and bowl. In cross-section the individual arms of these isolated parabolic dunes appear as low sand mounds with either flat bases, or at least gently undulating bases, or gently inclined bases, corresponding to the buried topography of a broadly undulating yellow sand plain. In some areas the cross-sections show Safety Bay Sand as a thin sheet with mound-like thickenings indicating local coalescense of the parabolic dunes. Older degraded solitary parabolic dunes may be reduced to low conical sand hills (the residual parabolic dune front) with loss of the trailing arms (Fig. 4). The final product of this type of geomorphic degradation is an isolated low-relief concial mound of calcareous sand.

In most areas humic soil had developed on yellow sand and the contact of the soil with overlying white Safety Bay Sand is sharp. In some local areas however, the white Safety Bay Sand may lie directly on yellow sand without an intervening soil sheet. In pits and trenches cut into the Safety Bay Sand large scale cross layering is evident and inclined to landward indicating the direction of migration of the advancing face of the parabolic dune.

Locally, the Holocene dune sands are weakly indurated by sparry calcite cement similar to the induration described in aeolian sands elsewhere in the world (Yaalon 1967, Bathurst 1975). These cements are thin epitaxial growths on grains and are thickest at grain contacts. The cements are forming in modern vadose environments in the southwestern coastal zone (Semeniuk 1983). In the yellow sand beneath the base of the Holocene dune sands there may be local development of rhizoconcretions where calcium carbonate from solutions derived from the calcareous dunes has precipitated around plant roots lodged in the *non calcareous* yellow sand. These rhizoconcretions are typically enveloped by a halo of bleached white quartz sand. Thus in the vicinity of its contact with carbonate sand yellow quartz sand is being transformed into a quartzose limestone. There also may be root

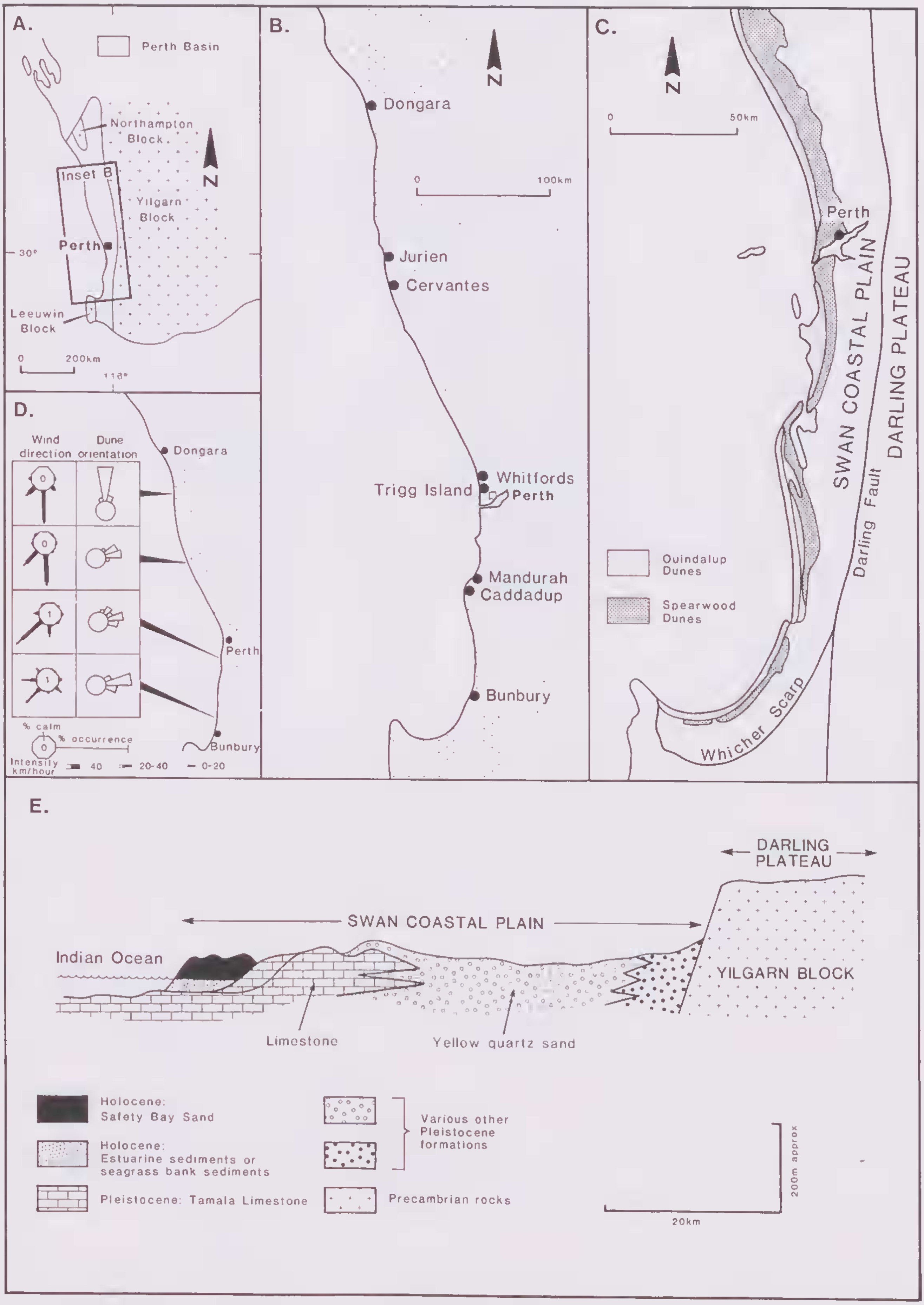

Figure 1.—Geological Setting. A Perth Basin (after Playford *et al* 1976). B Swan Coastal Plain and study sites. C Geomorphic units and shore-parallel extent of the Spearwood Dunes (after McArthur & Bettenay 1960). D Orientation of Holocene parabolic dune axes along the coastal zone (wind directions from Searle & Semeniuk 1985). E. Schematic section showing regional stratigraphic framework of the Swan Coastal Plain.

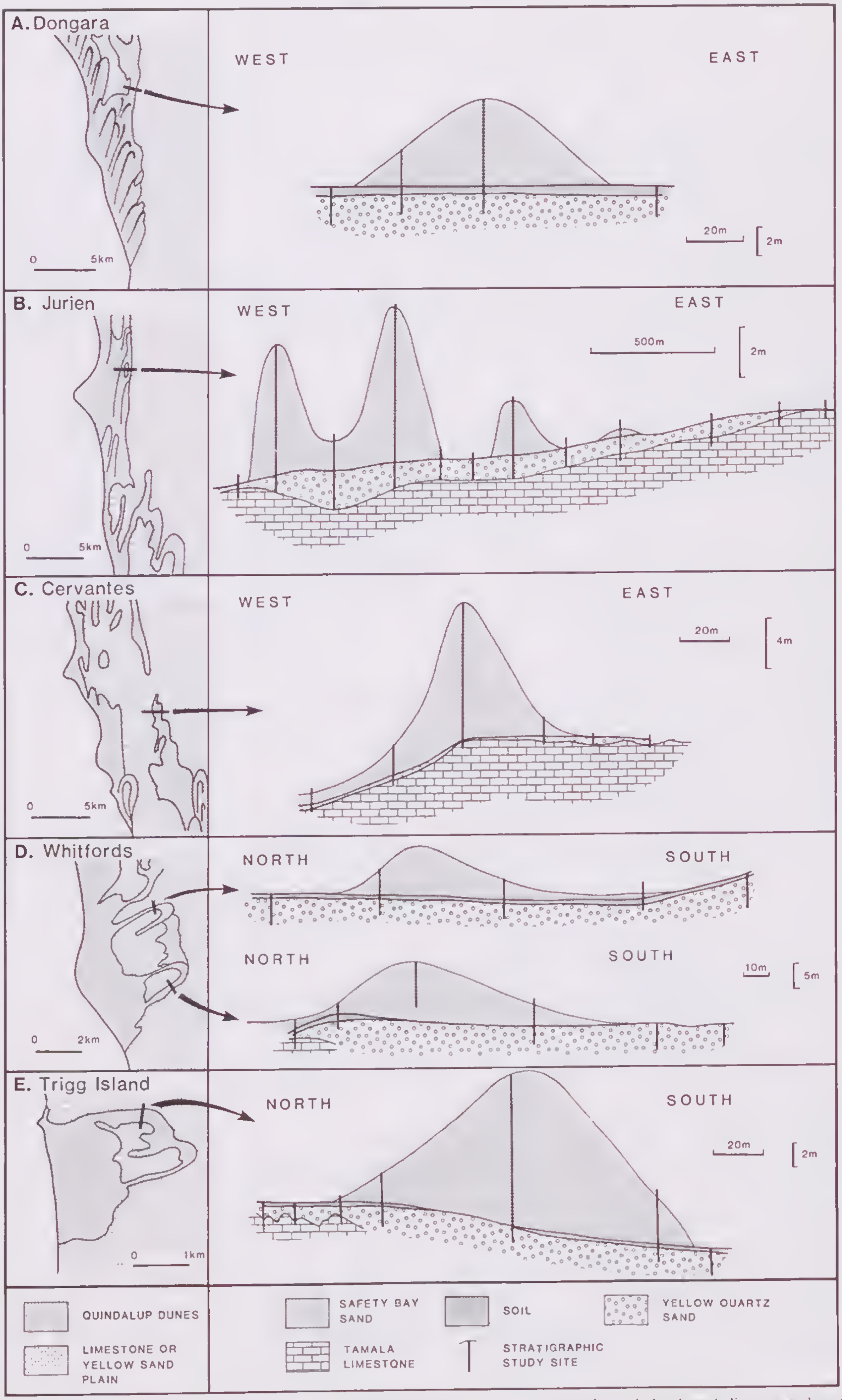

Figure 2.—Plan view and cross sections of Holocene coastal parabolic dunes showing attenuated dune forms, isolated parabolic arms, and stratigraphic profiles.

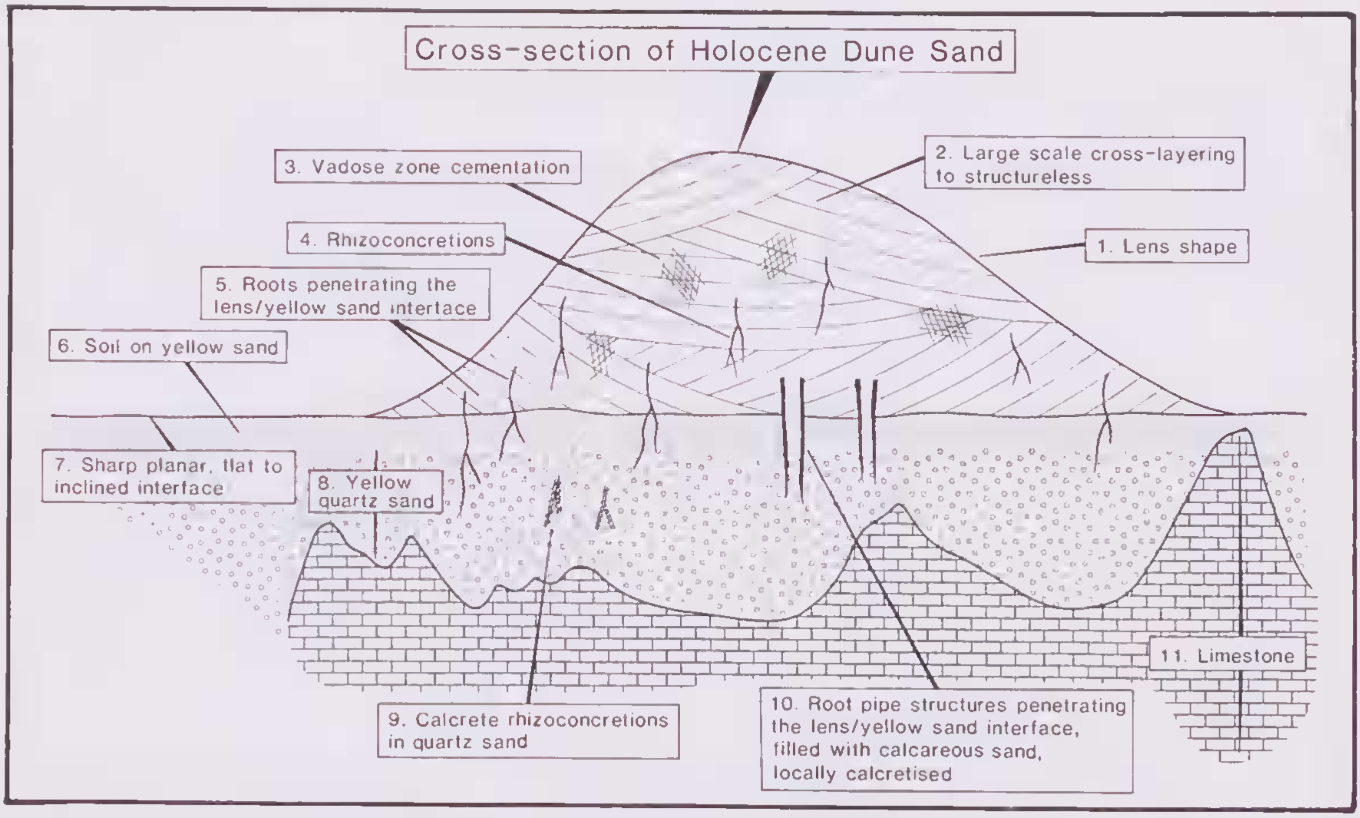

Figure 3.—Summary of key features of stratigraphic cross sections through Holocene parabolic dunes.

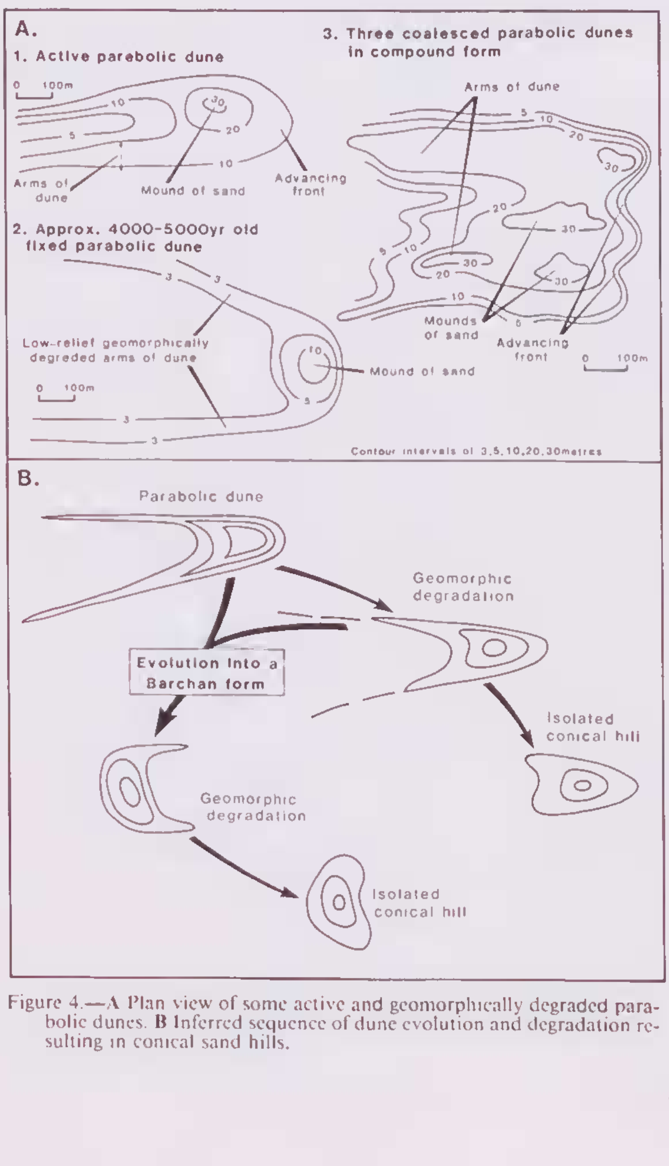

Figure 4.—A Plan view of some active and geomorphically degraded parabolic dunes. B Inferred sequence of dune evolution and degradation resulting in conical sand hills.

pipes which descend from the unlithified Holocene calcerous aeolian sand through the interface between the Holocene sand and yellow sand and into the yellow sand. These pipes are up to 20 cm diameter and are filled with calcareous aeolian sand infiltrated from above (Fig. 5).

Pleistocene Limestone Lenses in yellow sand

Limestone lenses have been studied in detail at 7 localities. The essential information on these lenses is summarized below (Figs. 6, 7 & 8):

1) The lenses are usually 2-5 m thick and up to 10 m thick; in cross-section they are up to 20-30 m wide and in places up to 150 m wide, tapering at their margins.

2) The limestone of the lens is typically aeolianite; it is cross laminated at the large scale with cross layering dipping to northeast, east and southeast, and contains abundant to common rhizoconcretions. This is important in that it is not a marine limestone that occurs as lenses. The limestone typically is medium sand-sized quartz skeletal grainstone cemented by sparry calcite typical of vadose environments.

3) The top of a lens, as defined by an enveloping surface, is convex, but in detail the top surface is sculptured by "solution" pipes and karren structures and impregnated with massive/laminar calcrete; these features are absent along the basal limestone/yellow sand interface.

4) Some of the larger lenses and lens margins have been segmented by karren structures.

5) Overall, the base of a lens is flat or semi-planar, but it is not necessarily horizontal; in detail it is flat or slightly hummocky with hummocks < 10 cm amplitude over a length of a metre; the basal contact may be modified (penetrated) by calcareous sand-filled root pipes and by yellow quartz sand-filled termite burrows.

6) The contact of limestone with underlying yellow sand is sharp and planar.

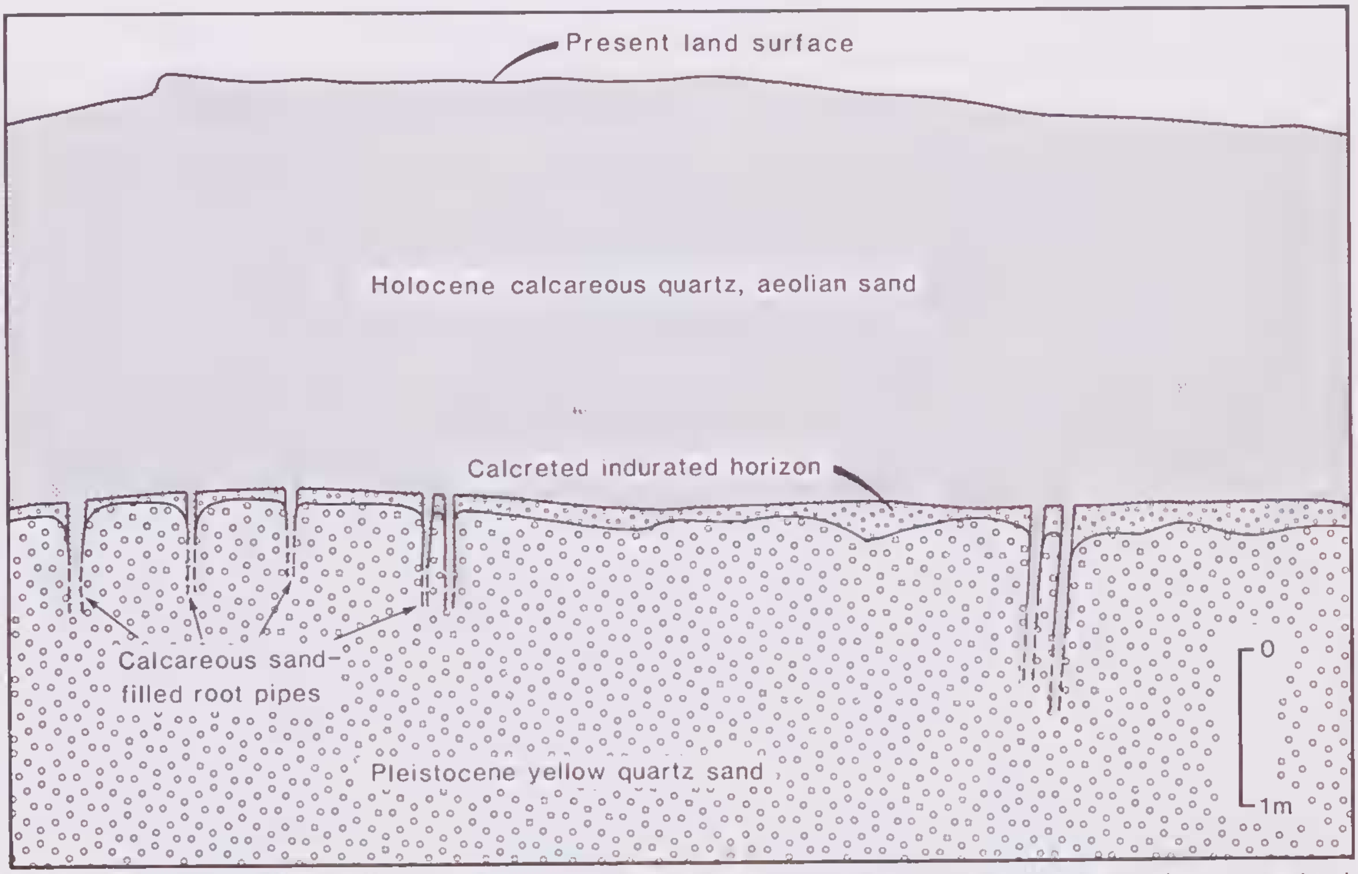

Figure 5.—Tracing from photograph showing relationship between unlithified Holocene calcareous aeolian sand and underlying yellow quartz sand in the Cervantes area. The sharp horizontal interface between them is a weak pedogenic surface, developed on the yellow sand, that has also been impregnated by incipient calcrete. The interface has been punctured by root pipes which are now filled with unlithified calcareous sand.

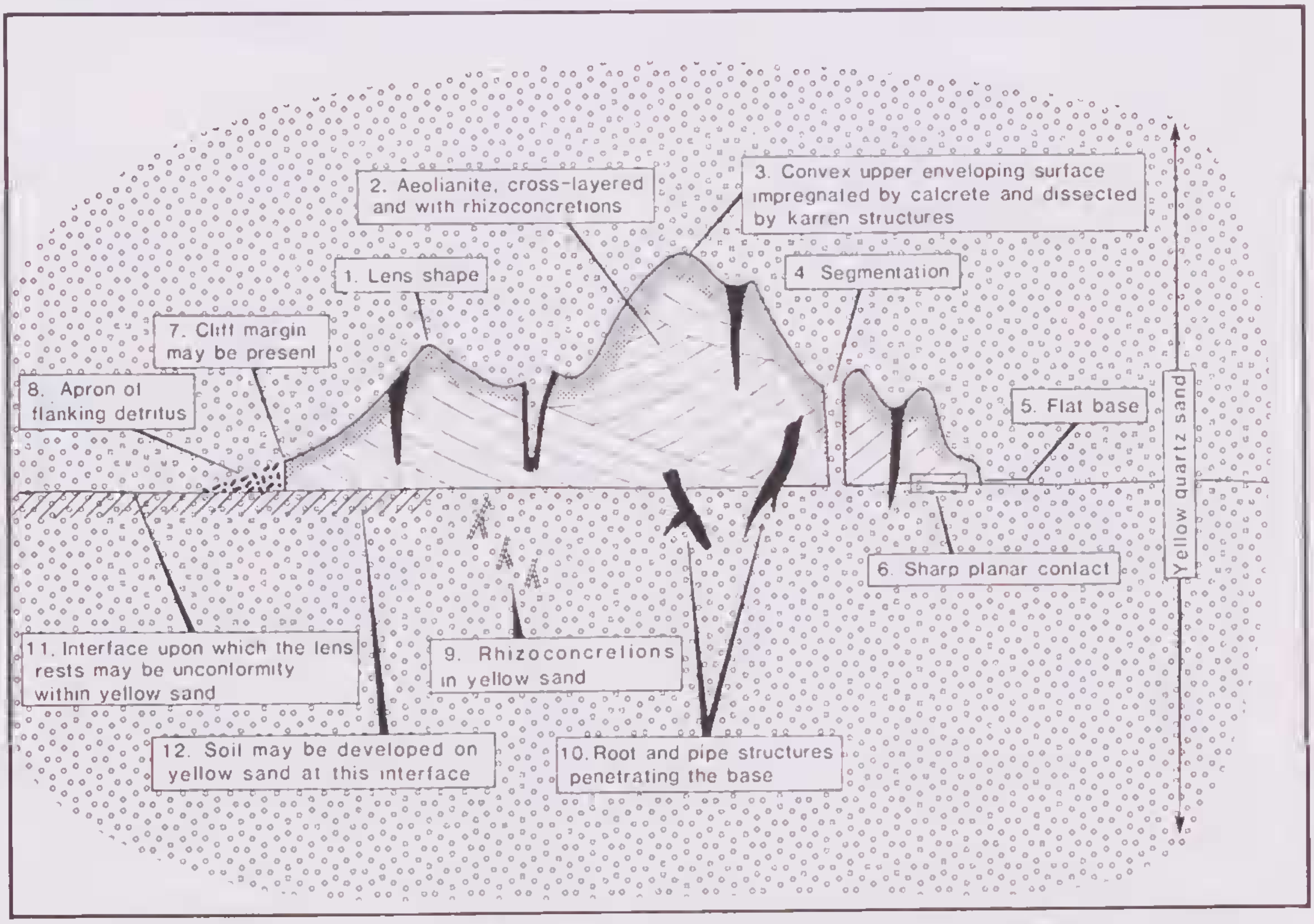

Figure 6.—Summary of key features of Pleistocene limestone lenses. Numbered annotations relate to the observations listed on pp 39-43 of text.

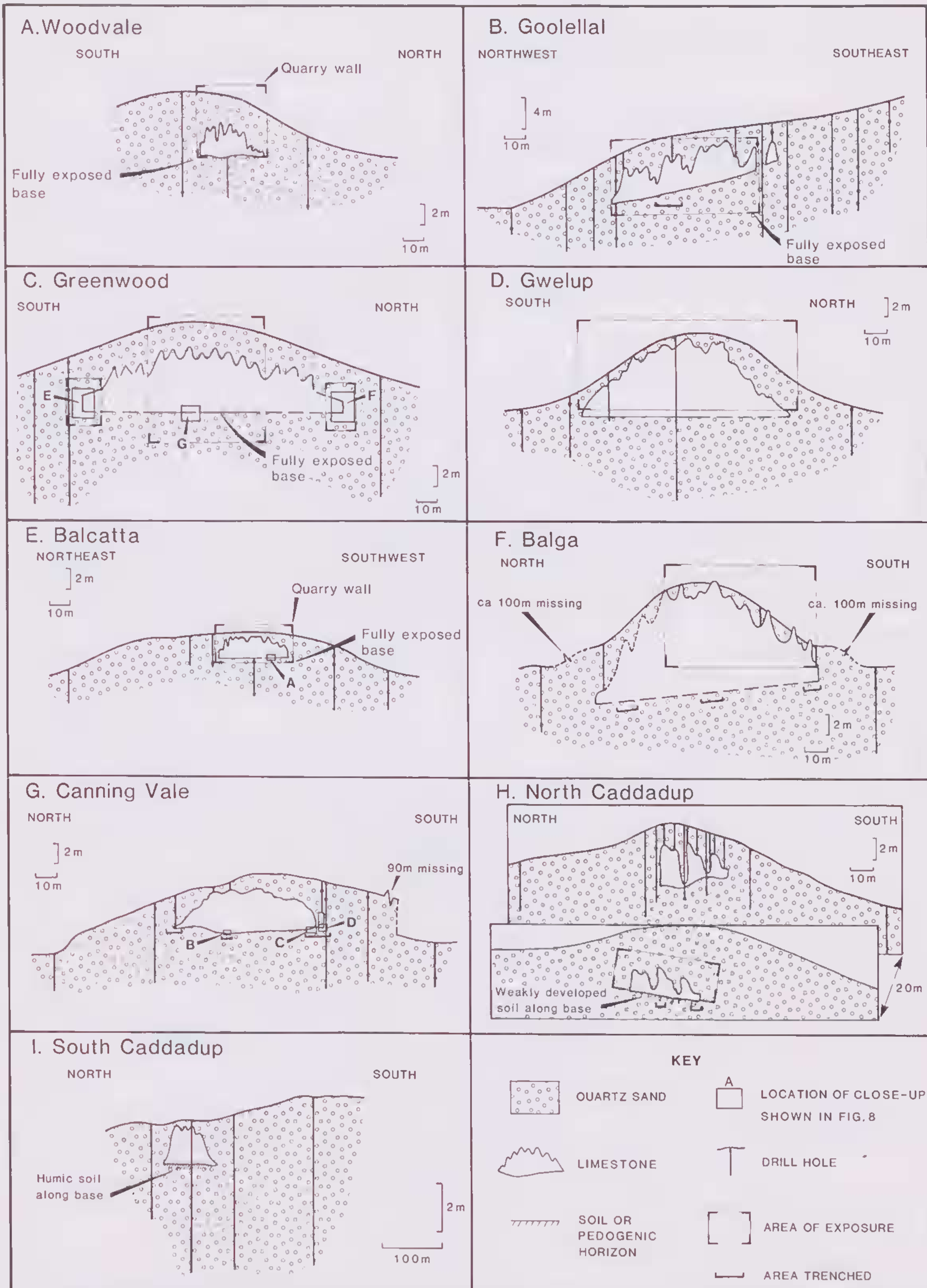

Figure 7.—Stratigraphic profiles of Pleistocene limestone lenses. Insets indicate where detail sections are illustrated in Fig. 8 Latitude and longitude locations of limestone lenses are: Woodvale 31°47′50″S. 115°48′00″E; Goolellal 31°48′20″S. 115°48′15″E; Greenwood 31°50′10″S. 115°47′50″E; Gwelup 31°52′00″S. 115°48′10″E; Balcatta 31°51′50″S. 115°48′20″E; Balga 31°52′05″S. 115°49′25″E; Canning Vale 32°04′25″S. 115°53′55″E; N. Caddadup 32°36′10″S. 115°38′10″E; S. Caddadup 32°36′30″S. 115°38′15″E.

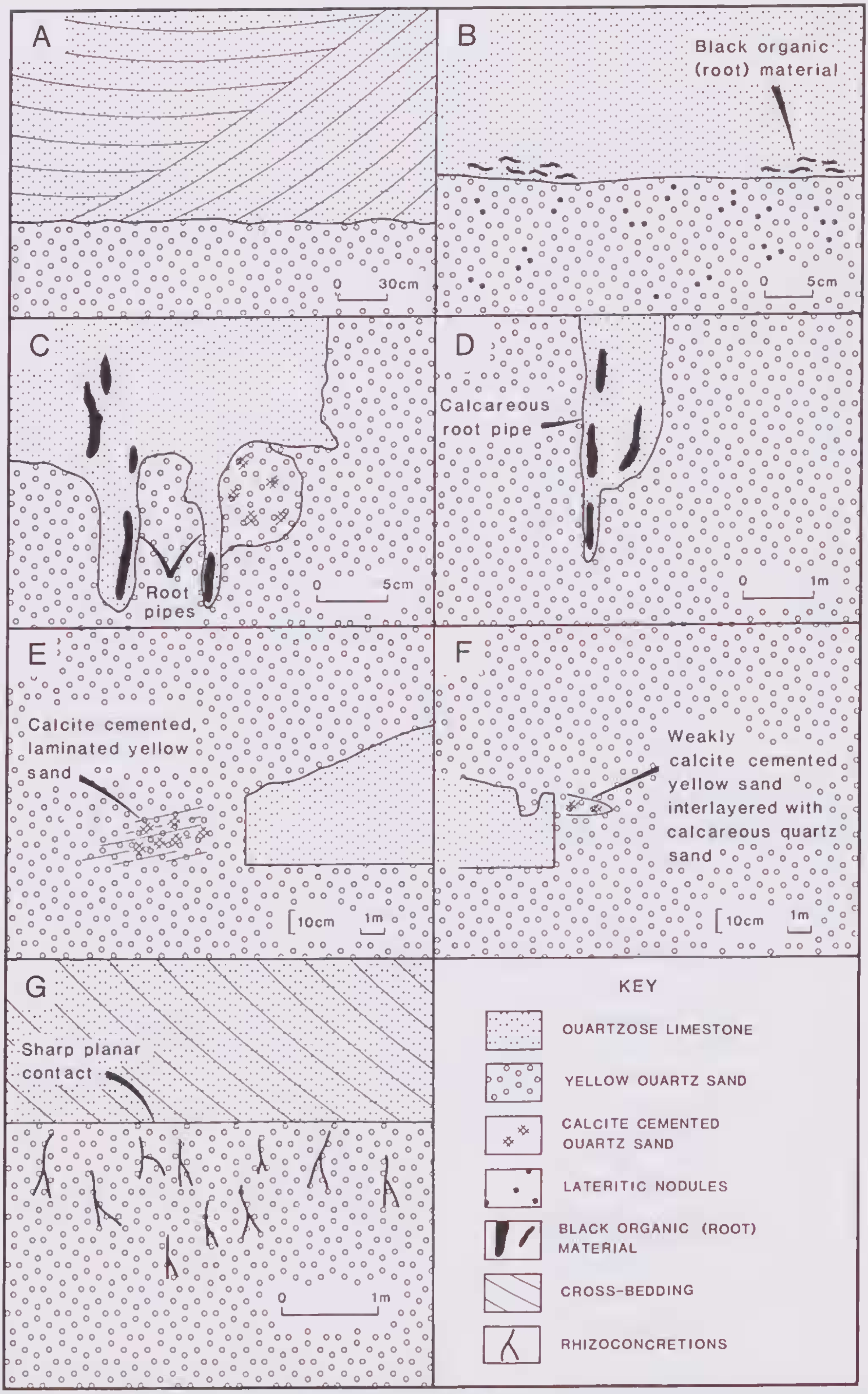

Figure 8.—Tracings from photographs showing details of stratigraphy at the contact between limestone lenses and encompassing yellow sand. **A, B & G** Planar sharp contact of base of limestone lens and underlying yellow sand. **G** Rhizoconcretions in underlying yellow sand. **C & D** Details of pipe structures penetrating the interface between limestone lens and underlying yellow sand. **E & F** Laminated apron deposit flanking a limestone lens.

7) Some lenses have cliff margins with the adjoining and encompassing yellow sand.

8) Laminated and cross laminated wedges and sheets of calcareous quartz sand interlayered with coarse and medium quartz sand form flanking aprons, 30-50 cm thick and several metres wide, around some lenses.

9) Calcareous rhizoconcretions cementing the yellow quartz sand may occur immediately below the limestone; these rhizoconcretions, consisting of calcrete and sparry calcite, impregnate a grain-supported yellow quartz sand; goethite pigmented (yellow) kaolin coatings on the yellow quartz grains are enveloped by the calcite cements.

10) The yellow sand immediately below the limestone lens may be penetrated for a limited distance (20-50 cm up to 1 m) by root casts and root pipes emanating from the limestone and they may be 1 cm, 10 cm or 20 cm in diameter, and be filled with calcareous sand infiltrated from the lens.

11) The limestone lens may directly overlie an unconformity, or bounding surface (see Talbot 1985), within the yellow sand marked by an extensive horizon of leached white sand, or coarse sand, or a pedogenic surface of clayey yellow sand or lateritic yellow sand.

12) Locally, the limestone lens rests on a humic soil developed on yellow sand.

The significance of each of the above observations on Pleistocene limestone lenses is presented in Table 1.

Table 1

Significance of the geological information on the limestone lenses

Observation	Interpretation	Significance
1. lens shape of limited size	mound-like sand body which, after lithification to limestone, would have resembled a limestone knoll	geometry of body reflects geometry of depositional form
2. internal structure of cross layering and rhizoconcretions, aeolianite lithology	typical aeolian accumulation and post depositional diagenesis	aeolian origin of the body and normal post-depositional diagenetic processes have operated
3. top of lens with pipes, karren structures and calcrete	solution modification of exposed surface or shallowly buried surface; root penetration to develop pipes; subaerial calcretization of surface of limestone	limestone lens had undergone alteration in subaerial environment, the top surface *not* the basal surface, has been modified subaerially
4. segmentation by karren structures	karren structures propagating downwards locally dissected the lenses	dissection results in steep-sided hollows and ultimately can result in cliff edges to the limestone lenses
5. flat base	aeolianite body encroached onto a sand plain	the contact between the limestone and underlying sand is depositional *not* solutional
6. sharp planar contact between limestone and underlying yellow quartz	aeolianite body encroached onto a sand plain with subsequent modification of contact by bioturbation	the contact is not solutional; small scale irregularities are due to vegetation and fauna effects
7. cliff margins to lenses	during weathering/erosion in the subaerial environment the lenses were undercut on their margins; undercutting may be due to solution at the quartz sand/limestone contact or to wind removal of adjoining/underlying quartz sand	typical expression of upstanding limestone bodies (or knolls) when underlain by non-calcareous materials, i.e. sharp vertical small to large cliff edge, not thinly tapering
8. aprons of detritus	residual quartz from subaerial solution and the more resistant carbonate grians accumulated as aprons around the limestone knoll	the margins of the lenses were subaerially exposed and the lenses (knolls) were exposed; only subsequently was the entire knoll and apron system buried by later influx of yellow quartz sand; overlying sand emplaced by transportation and is not the product of *in situ* decalcification.
9. calcareous rhizoconcretions in underlying quartz sand	carbonate dissolved from the limestone percolated through the vadose zone located in the limestone and underlying yellow quartz sand; plant roots utilising the vadose water precipitated rhizoconcretions in the limestone and in the underlying quartz sand	source of carbonate in the quartz sand is from overlying limestone; rhizoconcretions post-date emplacement of limestone onto yellow quartz sand.
10. penetration of the basal limestone/yellow sand contact by plant root structures and pipes filled with quartz carbonate sand	vegetation inhabiting the knolls emplaced their roots through the limestone, through the limestone/yellow sand interface, and into the yellow sand; later infiltration of calcareous quartz sand into the rotted roots developed the various sized pipes; the calcareous structures were subsequently calcretised	the limestone/yellow sand contact can be modified by plant root activity, however the overall lower contact between limestone and yellow sand is essentially planar
11. limestone rests on an unconformity	aeolianite body encroached onto quartz sand plain whose surface was pedogenically altered (i.e. bounding surface)	the lower limestone/yellow sand contact is depositional and not solutional
12. limestone rests on humic soil	aeolianite body encroached onto quartz sand plain whose surface was pedogenically altered	the lower limestone/yellow sand contact is depositional and not solutional

*Observations numbered 1-12 follow that in the text pp 39-43.

The cross-sections illustrated in the figures represent opportunistic profiles through lenses as exposed in quarries and determined by coring. Thus the cross-sections may represent only the margin of larger lenses, or may represent oblique profiles through elongate lenses (*e.g.* sites D & G). However in some locations (site C, E & H) the lenses were observed in entirety and the sections represent maximum width and thickness of a lens.

Interpretation of Pleistocene sequences

Many of the features described from Pleistocene sequences are direct equivalents of lenses of aeolian coastal sand (arms or rims of isolated parabolic dunes) overlying quartz sand sheets as described in the modern coastal setting.

Local palaeo-environmental interpretation

The Pleistocene limestone lenses are interpreted as geomorphic residuals of calcareous parabolic dune fronts and as cross-sections of the arms of parabolic dunes, or locally developed barchan dune bodies resting on a former yellow sand plain. Generally it appears that during the Pleistocene the aeolian sand encroached onto a yellow sand plain but locally, particularly in more humid southern areas, the aeolian sand encroached onto a yellow sand plain which had a soil profile. The calcareous dunes migrated from the coastal zone as attenuated parabolic forms and locally became detached from their source. At this stage a detached dune could develop into a small barchan. As such in a cross-section parallel to the coast the detached dunes now appear as flat-based lenses. Internally, the large scale cross layering in the lenses indicates gross landward migration.

Vadose zone cementation transformed the calcareous aeolian sand to limestone. Small scale (grain to grain) solution of calcium carbonate by meteoric water (Yaalon 1967, Bathurst 1975), the translocation of dissolved carbonate to levels lower in the vadose profile, and the utilisation of vadose water by plants resulted in the development of carbonate rhizoconcretions in the aeolian sand *and locally in the underlying yellow quartz sand.*

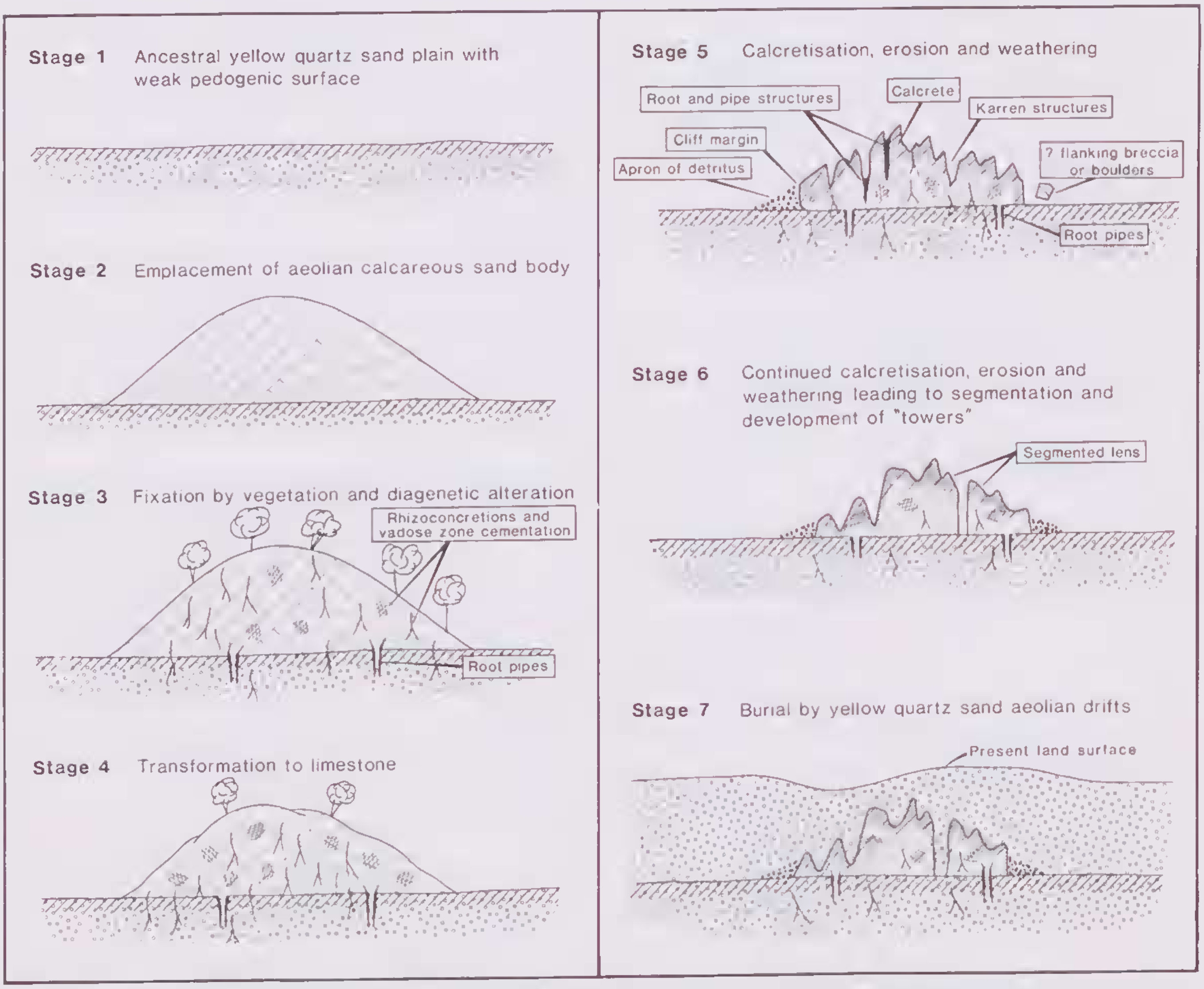

Figure 9.—Model depicting origin and stages in the alteration of limestone lenses. Note that burial by aeolian yellow quartz sand can take place at any stage and consequently terminate any further development of alteration stages. In addition, aeolian erosion may also exhume the limestone lenses and thus reinitiate the alteration sequence.

The limestone lenses have undergone subaerial weathering, subaerial solution, erosion and impregnation with calcrete. This resulted in a general overall cross-sectional volume reduction of the lens, in development of solution features such as karren and lapies structures (Bogli 1960, 1961, Jennings & Sweeting 1963, Sweeting 1972, Jakucs 1977, Estaban & Klappa 1983), and in development of a calcrete capstone. Larger scale subaerial solution and development of karren structure markedly modified the convex upper surface of the limestone to a series of steep-sided pinnacles and locally dissected the limestone lenses to an extent that the lenses become segmented. The segmented components would resemble miniature karst towers as described by Jakucs (1977). The inferred weathering/erosion history of the lenses is illustrated in Fig. 9. The features of the upper contact between limestone and yellow sand will be the subject of another paper.

Locally, cliff margins and perhaps flanking boulder/block deposits were developed where the limestone lens was undercut by wind deflation or rain wash of yellow sand, and collapsed along a cliffline. Weathering and sheet wash also resulted in the development of aprons, composed of quartz sand and resistant carbonate grains, both derived in part from the limestone, flanking the margins of lenses. Similar solution structures in subaerially exposed limestone and flanking detrital deposits derived from limestone outcrops, occur in semiarid to arid regions elsewhere (Jakucs 1979).

At all stages of weathering and erosion, the basal contact of the calcareous sand/limestone lens with underlying yellow sand was continually modified by vegetation roots and burrowing fauna such as termites. This resulted in infiltration of calcareous sediment *down* into the yellow sand via plant root holes and animal burrows, and in the translocation of yellow sand *up* into the calcareous sand or limestone via termite activities.

Coastal setting interpretation

The relationship between the major limestone ridges of the Spearwood Dunes and the outliers of limestone lenses represents a transition from a coastal zone to inland, essentially a coastal to continental transition. The Pleistocene coastal environment generated massive aeolian sand accumulations that developed as a large ridge. The ridge consisted of an overlapping series of parabolic dunes. This coastal dune ridge overlies an unconformity on limestone or on yellow sand (see Fig. 5 in Allen 1981). Further to landward the ancestral terrain would have consisted of limestone or yellow sand plain.

Staggered advances of discrete parabolic dunes emanated from the coastal zone and encroached onto the adjoining ancestral hinterland terrain. These parabolic dunes extended up to several kilometres from their source and locally became detached. As such they represent the extremities of the influence of coastal environment sedimentation.

Gross stratigraphic interpretation

The stratigraphic relationship of limestone lenses in a regional setting represents a transition zone between two major lithofacies, a marine derived coastal carbonate facies, and a land derived continental yellow quartz sand facies. Such a setting is not unusual in the geological record: as Glennie (1970: 121) points out "it is important to realise that continental (desert) shoreline and marine facies may all occur in close proximity".

The gross stratigraphic setting of this coastal region is interpreted as one of periodic yellow sand incursions from the east by aeolian transport during glacial periods associated with aridity and lower sea levels, alternating with coastal aeolian building during interglacial periods (following Fairbridge 1964, Kukla 1977, Sarnthein 1978, Sprigg 1979, Glassford 1980) associated with wetter climates and elevated sealevels. Thus during glacial-age desert phases yellow sand incursions would have extended onto the exposed continental shelf.

During an interglacial the sediments of the shoreline environment were composed of sand derived from reworking of the former sand plain (quartz and some felspar), reworking of pre-existing limestone ridges (lithoclasts) and contribution of resident/nearby fauna (skeletons). The quartzose calcareous sand was piled into a dune ridge along the Pleistocene shoreline. From this main ridge parabolic dunes extended inland forming isolated arms and mounds of quartzose calcareous sand. Later, induration by calcite cementation converted these aeolian sands to limestone.

During the ensuing glacial period yellow sand aeolian drifts blanketed the entire coastal zone burying the limestone lenses and the main limestone ridge. Since its last major mobilisation the yellow sand has been variously podzolized, bioturbated and locally reworked by aeolian, fluvial, lacustrine and marine processes.

The stratigraphic array and the dynamics of the gross system is interpreted as an interacting and alternating system of desert aeolian sand influx (following Killigrew & Glassford 1976, Glassford & Killigrew 1976, Glassford 1980) and marine (coastal) reworking. The model is summarized in Fig. 10. Successive alternating episodes of desert aeolian influx and marine reworking would result in a thick section of yellow quartz sand on the east portion of the Spearwood (limestone) ridges with scattered limestone lenses within the yellow sand body.

The zone of limestone lenses in a given time interval would represent the transitional zone between coastal dunes and ancestral hinterland where local coastal aeolian incursions penetrated a limited extent to inland (for analogous topographic and coastal settings see Glennie 1970, Fryberger & Ahlbrandt 1979 and Fryberger *et al.* 1983). As such the contact between limestone ridges and hinterland yellow sand (i.e. between Tamala Limestone and Bassendean Sand) may not necessarily be a straight north-south junction. Rather, it will be an irregular to disjointed contact, and in many places the contact will be a transitional zone of lenses.

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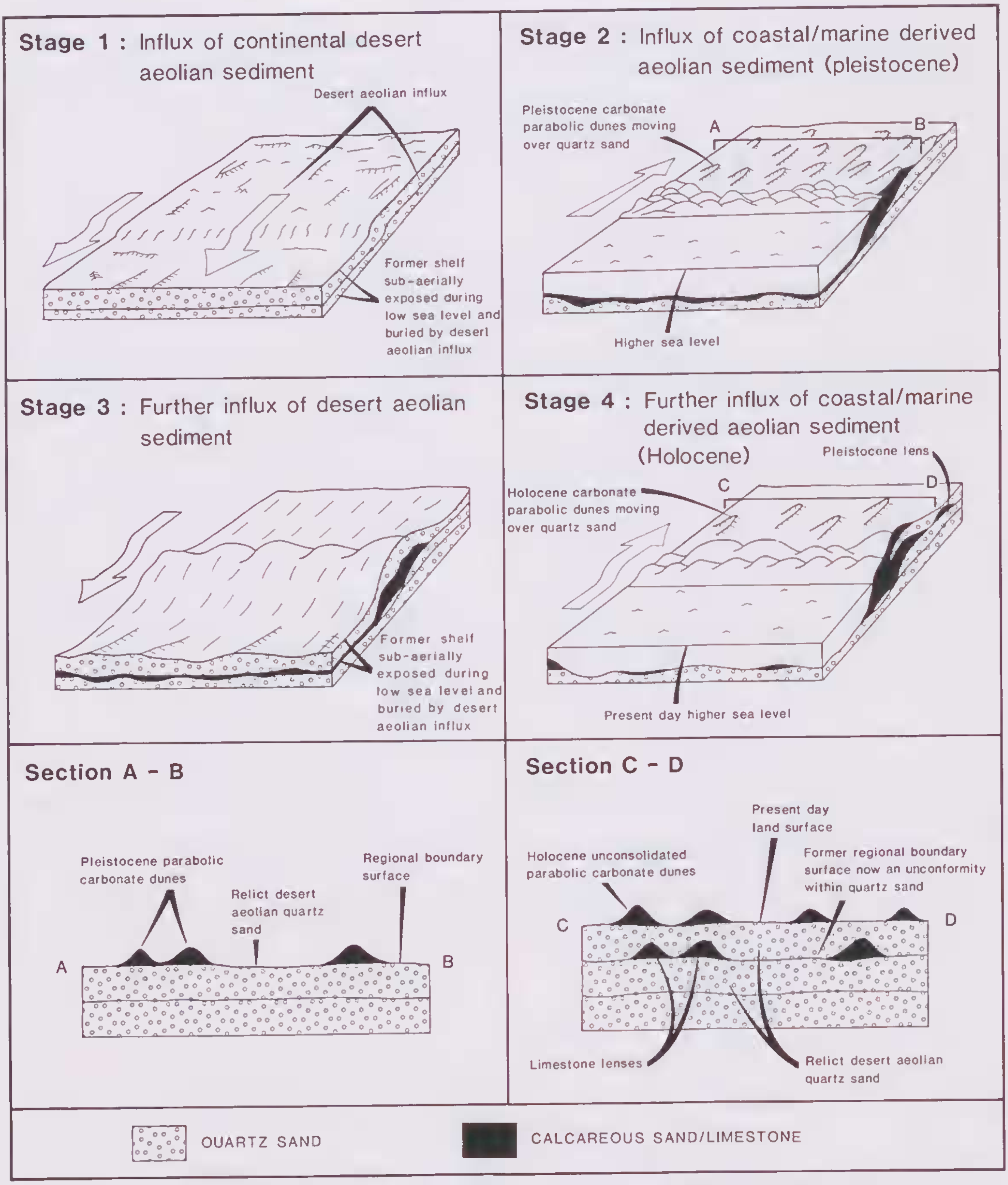

Figure 10.—Model depicting alternating phases of desert aeolian influx during glacial periods and coastal dune accumulation during interglacial periods. Limestone lenses reflect the transition zone between coastal aeolian accumulations and the continental aeolian facies.

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